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DALITZ PLOT ANALYSES AT CLEO-C

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Abstract

We present several recent analyses of Dalitz plots from the CLEO-c experiment, including published and preliminary analyses of $D^+ \rightarrow \pi^- \pi^+ \pi^+$, $D^+ \rightarrow K^- \pi^+ \pi^+$, and $D^0 \rightarrow K_{S,L}^0 \pi^+ \pi^-$ decays. More information on these analyses can be found in References ^{1, 2, 3}). New preliminary analyses we present include a search for CP asymmetry in $D^+ \rightarrow K^+ K^- \pi^+$ decays and a Dalitz plot analysis of $D^0 \rightarrow K_S^0 \pi^0 \pi^0$.

We report on a search for the CP asymmetry in the singly Cabibbo-suppressed decay $D^+ \rightarrow K^+ K^- \pi^+$ using a data sample of 572 pb^{-1} accumulated with the CLEO-c detector and taken at the $e^+e^- \rightarrow \psi(3770)$ resonance. We have searched for CP asymmetries using a Dalitz plot based analysis that determines the amplitudes and relative phases of the intermediate states.

We also use a 281 pb^{-1} CLEO-c data sample taken at the $e^+e^- \rightarrow \psi(3770)$ resonance to study the $D^0 \rightarrow K_S^0 \pi^0 \pi^0$ Dalitz plot. Our nominal fit includes the K_S^0 , $K^*(892)$, $f_0(980)$, $f_0(1370)$, and $K^*(1680)$ resonances.

1 Search for CP asymmetry in $D^+ \rightarrow K^+ K^- \pi^+$ Decays

Singly Cabibbo-suppressed (SCS) D -meson decays are predicted in the Standard Model (SM) to exhibit CP -violating charge asymmetries smaller than the order of 10^{-3} . Direct CP violation in SCS decays could arise from the interference between tree-level and penguin processes. Doubly Cabibbo-suppressed and Cabibbo-favored (CF) decays are expected to be CP invariant in the SM due to the lack of contribution from penguin processes. Measurements of CP asymmetries in SCS processes greater than $\mathcal{O}(10^{-3})$ would be evidence of physics beyond the SM ⁴⁾.

We define two variables: the energy difference $\Delta E \equiv \sum_i E_i - E_{\text{beam}}$ and the beam-constrained mass $m_{\text{BC}} \equiv \sqrt{E_{\text{beam}}^2 - |\sum_i \vec{P}_i|^2}$, where E_i , \vec{P}_i are the energy and momentum of each D decay product, and E_{beam} is the beam energy. We define a signal box corresponding to 2.5 standard deviations in each variable, and remove multiple candidates in each event by choosing the candidate that gives the smallest $|\Delta E|$. We obtain 13693 ± 137 $D^+ \rightarrow K^+ K^- \pi^+$ signal candidates. To reduce smearing effects introduced by the detector, a mass constraint fit for the D^+ candidate is applied to obtain the mass squared variables, $m_{K^+ \pi^+}^2$ and $m_{K^- \pi^+}^2$, for the $D^+ \rightarrow K^+ K^- \pi^+$ Dalitz plot (DP) shown in Figure 1(a).

The decay amplitude as a function of DP variables is expressed as a sum of two-body matrix elements and one non-resonant (NR) decay amplitude ⁵⁾. For most resonances, the matrix element is parameterized by Breit-Wigner shapes that take into account D meson and intermediate resonance form factors and angular dependence. For the $f_0(980)$ we use a Flatté function ⁶⁾. For the $a_0(980)$, we use the function in Ref. ⁷⁾. We choose the same phase conventions for the intermediate resonances as the E687 Collaboration ⁸⁾. A fit fraction (FF), the integral of a single component divided by the sum of all components, is reported for each intermediate resonance to allow for more meaningful comparisons between results.

For D^+ decays to $K^- \pi^+$ S -wave states, we consider three amplitude models. One model uses a coherent sum of a uniform non-resonant term and Breit-Wigner term for the $K_0^*(1430)$ resonance. The second model only uses a Breit-Wigner term for the $K_0^*(1430)$ resonance. The third model uses the LASS amplitude for $K^- \pi^+ \rightarrow K^- \pi^+$ elastic scattering ^{9, 10)}. We present

results only for the third model, although the first model provides a similar fit.

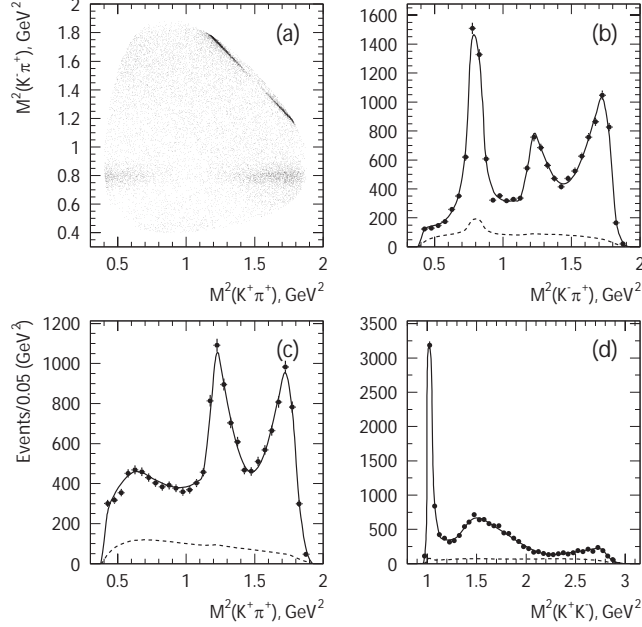


Figure 1: *The results of fitting the $D^+ \rightarrow K^+ K^- \pi^+$ data for Model three. (a) The scatter plot for squared mass of $K^- \pi^+$ versus $K^+ \pi^+$ and the projections onto squared mass of (b) $K^- \pi^+$ (c) $K^+ \pi^+$ and (d) $K^+ K^-$ for both fit (curve) and data (points) are shown. The dashed line shows the background contribution.*

We determine the detection efficiency as a function of the two DP variables by fitting a signal MC sample generated with a flat distribution in the phase space. We use a fit to the events in the ΔE sideband ($24 < |\Delta E| < 42$ MeV and $|m_{\text{BC}} - m_{D^+}| < 9$ MeV/ c^2) to describe the background distribution of the DP. Having information for both the background and efficiency, as well as the fraction of signal events in the signal region, we fit the data in the DP to extract the amplitudes and phases of any contributing intermediate resonances. We perform an unbinned maximum likelihood fit. The signal fraction f is $f_0 = (84.1 \pm 0.2)\%$, constrained in the fit to be within its error σ_f obtained from the fit to the m_{BC} distribution. We begin by fitting the DP with all known resonances that may possibly contribute to this decay. We determine

Table 1: *The fit results in Model three. The errors shown are statistical, experimental systematic, and modeling systematic respectively.*

Component	Amplitude	Phase ($^{\circ}$)	Fit Fraction (%)
$\bar{K}^*(892)^0 K^+$	1(fixed)	0(fixed)	$23.9 \pm 0.6^{+0.1+0.9}_{-0.3-0.4}$
$K^-\pi^+(S)K^+$	$4.53 \pm 0.16^{+0.22+0.31}_{-0.01-0.23}$	$21 \pm 3^{+0+7}_{-6-2}$	$53 \pm 3^{+5+8}_{-0-5}$
$a_0(980)\pi^+$	$0.74 \pm 0.09^{+0.03+0.16}_{-0.01-0.39}$	$96 \pm 7^{+0+4}_{-4-15}$	$1.7 \pm 0.4^{+0.1+1.3}_{-0.0-0.6}$
$\phi(1020)\pi^+$	$1.23 \pm 0.02^{+0.00+0.01}_{-0.00-0.02}$	$-148 \pm 3^{+1+5}_{-1-3}$	$28.0 \pm 0.5^{+0.0}_{-0.4} \pm 0.5$
$f_2(1270)\pi^+$	$0.91 \pm 0.13^{+0.03+0.11}_{-0.01-0.24}$	$20 \pm 6^{+5+9}_{-0-11}$	$0.9 \pm 0.2^{+0.1}_{-0.0} \pm 0.2$
$a_0(1450)\pi^+$	$1.36 \pm 0.10^{+0.20+0.45}_{-0.01-0.25}$	$116 \pm 5^{+1+13}_{-5-10}$	$3.4 \pm 0.5^{+1.0+2.5}_{-0.0-1.2}$
$\phi(1680)\pi^+$	$2.6 \pm 0.3^{+0.2+0.6}_{-0.0-0.7}$	$-96 \pm 10^{+0+17}_{-16-12}$	$0.89 \pm 0.18^{+0.15+0.3}_{-0.02-0.2}$
$\bar{K}_2^*(1430)^0 K^+$	$3.5 \pm 1.0^{+1.6+1.6}_{-0.0-2.6}$	$-156 \pm 6^{+1+30}_{-0-8}$	$2.1 \pm 1.2^{+2.4+2.2}_{-0.0-1.3}$

which resonances are to be included by maximizing the fit confidence level (C.L.). The procedure is to add all possible resonances, then subsequently remove those which do not contribute significantly, or worsen our C.L. The projections of the DP for the fit to Model three are shown in Figures 1(b-d). The results of the fit amplitudes, phases, and fractions including errors are shown in Table 1 for Model three.

Table 2: A_{CP} for each component of the fit using D^{\pm} samples in Model three. The errors for fit fractions and phases are statistical only, and those for A_{CP} are statistical, experimental systematic, and modeling systematic respectively.

Component j	$A_{CPj}(\%)$
$\bar{K}^*(892)^0 K^+$	$-0.1 \pm 2.9^{+2.3+0.7}_{-0.4-0.4}$
$K^-\pi^+(S)K^+$	$-1 \pm 5^{+1+6}_{-2-4}$
$a_0(980)\pi^+$	$-11 \pm 23^{+4+24}_{-9-6}$
$\phi(1020)\pi^+$	$-3.0 \pm 1.9^{+0.1+0.2}_{-0.2-0.3}$
$f_2(1270)\pi^+$	$4 \pm 25^{+3+22}_{-4-46}$
$a_0(1450)\pi^+$	$-18 \pm 14^{+0+16}_{-8-9}$
$\phi(1680)\pi^+$	$-9 \pm 21^{+22+7}_{-4-3}$
$\bar{K}_2^*(1430)^0 K^+$	$69 \pm 51^{+1+8}_{-28-41}$

To search for CP violation in this model, we fit the D^+ and D^- samples independently. We use the same background fraction and PDF as those used in the fit to the total sample, but different coefficients for efficiency functions which are obtained from signal MC of D^{\pm} decays. The calculated CP asymmetry, $A_{CPj} \equiv \frac{FF_{jD^+} - FF_{jD^-}}{FF_{jD^+} + FF_{jD^-}}$, is shown for each resonance j in Table 2.

2 Dalitz Plot Analysis of $D^0 \rightarrow K_S^0 \pi^0 \pi^0$ Decays

The PDG ¹¹⁾ has little information on the $D^0 \rightarrow K_S^0 \pi^0 \pi^0$ decay. In addition to providing a more comprehensive study of the $D^0 \rightarrow K_S^0 \pi^0 \pi^0$ decay, this DP analysis seems like a good place to look for the low mass $\pi\pi$ S -wave signature of the σ . The $K_S^0 \pi^+ \pi^-$ mode is much cleaner and has better statistics, but the ρ^0 resonance overlaps the region where we would expect to find the low mass S -wave signature. Using CLEO-c data, we eliminate nearly all of the background by doing a double-tagged analysis, where both D mesons are completely reconstructed.

We have analyzed 281 pb⁻¹ of CLEO-c data taken on the $e^+e^- \rightarrow \psi(3770)$ resonance. In a double-tagged analysis, both D mesons are reconstructed. For our double-tagged analysis, we consider candidates with one D reconstructed as $K_S^0 \pi^0 \pi^0$, and the other D reconstructed using any of the following decay modes (charge conjugation is implied throughout this analysis): $\overline{D}^0 \rightarrow K^+ \pi^-$, $\overline{D}^0 \rightarrow K^+ \pi^- \pi^0$, $\overline{D}^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$. In a single-tagged analysis, we reconstruct only one D meson in the event, which decays to $K_S^0 \pi^0 \pi^0$.

Table 3: $D^0 \rightarrow K_S^0 \pi^0 \pi^0$ signal yield, number of candidates, and signal fraction

Result	Double Tag	Single Tag
Signal Yield	257 ± 17	1884 ± 56
Total Candidates	276	2548
Signal Fraction	0.931 ± 0.062	0.739 ± 0.022

To reduce 2π background that fakes a K_S^0 , we enforce a 2σ enhanced flight significance selection criteria on our K_S^0 candidates. To reduce the $K\pi\pi^0$ background, we require $|dE/dx_{pion}| < 3\sigma$ and $dE/dx_{kaon} < -2\sigma$ for both K_S^0 daughter pions. We use the same particle identification selection criteria for double-tagged and single-tagged analyses. We apply a 2σ selection criteria on the reconstructed K_S^0 mass. After enforcing our selection criteria on the K_S^0 mass, we apply a 2σ selection criteria on ΔE . We additionally apply a 2σ cut on the beam constrained mass. For each event that has more than one candidate, we require the following: For the double-tagged data, we take the average of the signal beam constrained mass and the tagged beam constrained mass, and we select whichever candidate's average is closest to the nominal D

mass. For the single-tagged data, we select the candidate with ΔE closest to zero. Table 3 shows our signal yield and signal fraction.

For this analysis, we define our DP variables as follows: $x \equiv \text{larger } m_{K_S^0 \pi^0}^2$, $y \equiv m_{\pi^0 \pi^0}^2$, $z \equiv \text{smaller } m_{K_S^0 \pi^0}^2$. When fitting such a Dalitz plot, we must take into account the fact that the two π^0 final state particles are indistinguishable, so we explicitly symmetrize the functions we use in x and z .

To study the efficiency of reconstructing our signal, we generate 100000 signal Monte Carlo events distributed uniformly across the Dalitz plot phase space. Half of these events force the D^0 to decay directly into $K_S^0 \pi^0 \pi^0$ and the \bar{D}^0 to decay into neutrinos. The other half of these events force the \bar{D}^0 to decay directly into our signal mode and the D^0 to decay into neutrinos. We fit the efficiency over the Dalitz plot to a third-order polynomial explicitly symmetric in x and z . To fit for the background, we use a sideband from single-tagged data which is centered $5\sigma_{m_{D^0}}$ lower in m_{BC} than the signal region, with the same width as that of the signal region, and has the appropriate range in ΔE which conserves the boundaries of the signal DP. We use this background shape for the double-tagged data as well as for the single-tagged data. We fit the background events to a third-order polynomial explicitly symmetric in x and z , plus a non-interfering $K^*(892)$ Breit-Wigner in both x and z .

The signal is parameterized with an isobar model that has four interfering resonances plus one non-interfering resonance. To enforce the symmetry requirement in the DP, we include each K^* resonance as an x resonance and a z resonance, while using the same amplitude and phase for the x contribution and z contribution. The parameters for the K_S^0 , $K^*(892)$, and $K^*(1680)$ come from the PDG^[11]. The parameters for the $f_0(980)$ are approximated from a BES paper^[12]. The parameters for the $f_0(1370)$ come from Reference^[13].

Figure 2(a) displays the DP from the double-tagged data. To fit this DP with an unbinned maximum likelihood fitter, we fix the signal fraction to 0.931 as determined from the beam constrained mass distribution. The fit also fixes the efficiency parameters and background parameters as determined from the signal Monte Carlo and sideband. The fit determines the amplitudes and phases of the resonances and calculates the fit fractions. Figure 2(b) shows the fit results.

To estimate systematic errors, we use the technique developed by Jim Wiss and Rob Gardner^[14]. Using this technique, the systematic errors are

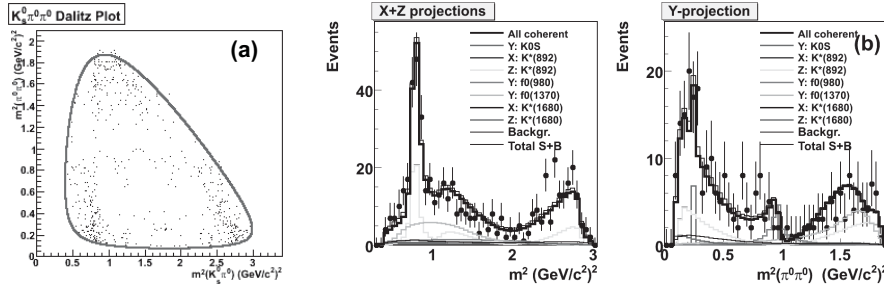


Figure 2: (a) Dalitz plot of the double-tagged data (2 entries per candidate, second entry has x and z swapped) and (b) fits to the double-tagged $x+z$ projection and double-tagged y projection.

essentially independent of the number of systematic sources considered¹⁴). Table 4 gives our preliminary results. We are currently extending our analysis to the full available CLEO-c $\psi(3770)$ data sample, and studying the effects of using a σ or κ S -wave to possibly improve our fit.

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4 References

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Table 4: *Final results including systematic errors. The first error is statistical. The second error is systematic arising from our selection criteria. The third error is systematic arising from our signal model.*

resonance		double tag
K_S^0	Fit Fraction	$0.026 \pm 0.023 \pm 0.003 \pm 0.001$
	Amplitude	$0.101 \pm 0.029 \pm 0.009 \pm 0.004$
	Effective Width	$0.0046 \pm 0.0011 \pm 0.0001 \pm 0.0001$
$K^*(892)$	Fit Fraction	$0.542 \pm 0.054 \pm 0.030 \pm 0.053$
	Amplitude	1 (fixed)
	Phase ($^\circ$)	0 (fixed)
$f_0(980)$	Fit Fraction	$0.090 \pm 0.032 \pm 0.009 \pm 0.027$
	Amplitude	$1.50 \pm 0.27 \pm 0.10 \pm 0.20$
	Phase ($^\circ$)	$12 \pm 17 \pm 14 \pm 8$
$f_0(1370)$	Fit Fraction	$0.238 \pm 0.071 \pm 0.047 \pm 0.086$
	Amplitude	$2.77 \pm 0.45 \pm 0.30 \pm 0.66$
	Phase ($^\circ$)	$344 \pm 10 \pm 10 \pm 18$
$K^*(1680)$	Fit Fraction	$0.114 \pm 0.027 \pm 0.021 \pm 0.032$
	Amplitude	$4.55 \pm 0.68 \pm 0.49 \pm 0.59$
	Phase ($^\circ$)	$97 \pm 20 \pm 17 \pm 13$

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